

## Finite Element Modeling of Crustal Deformation in the Loma Prieta Region

Award No. 14-08-0001-G1852

Eugene Humphreys and Ray Weldon  
Department of Geological Sciences  
University of Oregon  
Eugene, Oregon 97403

(503) 346-5575

We have examined two aspects of Bay-area crustal deformation through the use of 3-D, visco-elastic finite element modeling of faulted crust (Figure 1 shows the model):

- (1) By driving the crustal model with various velocity distributions at the base of the lower crust, we have addressed the driving stresses of the transform system in the Bay area; in particular, we examine whether the upper crustal blocks are driven by stresses transmitted laterally through the elastic upper crust or by stresses transmitted up from the mantle lithosphere through the viscous lower crust.
- (2) By requiring consistency among geodetically-determined far-field motion, geologically- and geodetically-estimated fault slip rates, and some notion of crustal physical deformation processes, we have estimated the Bay-area crustal kinematics of the upper (faulted) crust and of the lower (viscous) crust.

Our models are limited in scope. We *assume* that Moho velocities parallel the Pacific-Sierra Nevada relative motion vector of Argus and Gordon. We *assume* an elastic upper crust that is broken with faults of zero shear strength, and a lower crust that is of constant viscosity. If faults have a laterally constant shear strength, a regional field of shear stress would result that could be superimposed to obtain a complete solution; however, if significant variations in lateral fault strength exist, we have not modeled this potentially important aspect of the problem. Also, by not modeling a lower crust of laterally-variable viscous strength, we cannot address how these strength variations trade off with variations in the driving velocity field at the base of the crust to produce the observed surface kinematics. Thus, our models represent the kinematics and dynamics of a crust where lateral variations in both fault strength lower crustal viscosity are not controlling the physics of deformation.

Figure 2 shows the velocity field and fault slip rates at the surface of the earth for the best model (as measured by the  $L_1$  misfit from the geologic and geodetic data). Under the restrictions of these assumptions, we conclude that driving forces come from below, and that the mantle shear zone is essentially a fault located at  $X = 80$  km (i.e., Figure 1c, lowest curve on right hand side). However, even in this case we cannot concentrate surface deformation as narrowly as it occurs (note relatively high rates for Hosgri and Calaveras-Hayward systems in Figure 2). By including a fault strength that has friction increasing with fault-normal stress, the San Andreas through the restraining Loma Prieta region would be relatively strong: this would tend to broaden the deformation zone yet further. We conclude that a mechanism tending to concentrate a shear load on the San Andreas, such as a low-strength zone of lower crust beneath the San Andreas or a more northwesterly-oriented mantle shear zone, is likely.

More robust conclusions can be drawn from the kinematic aspects of the model. Surface kinematics imply an uplift field, which is shown in Figure 3 for the model discussed in Figure 2. Note that predicted Loma Prieta region uplift rate is  $\sim 2$  mm/yr relative to the surrounding country (which is subsiding at  $\sim 1$  mm/yr). Figure 4 shows the velocity difference between the viscous layer (at 20 km depth) and the elastic plate. As shown in Figure 5, this results from vertical gradients of the horizontal velocity in the lower crust. Thus, these velocity differences are proportional to the

horizontal tractions acting on the base of the elastic layer. The difference in velocity is greatest in the Loma Prieta region, where it is oriented roughly normal to the regional shear field. Although greatest in the Loma Prieta region, similar margin-normal basal tractions are seen beneath wedge tips in general. These tractions will further strengthen restraining bends and weaken releasing bends in regions of fault coalescence. In the lower crust beneath Loma Prieta, the velocity gradient would cause an initially-vertical San Andreas fault to shallow in dip towards the southwest at a rate of a few degrees per m.y.

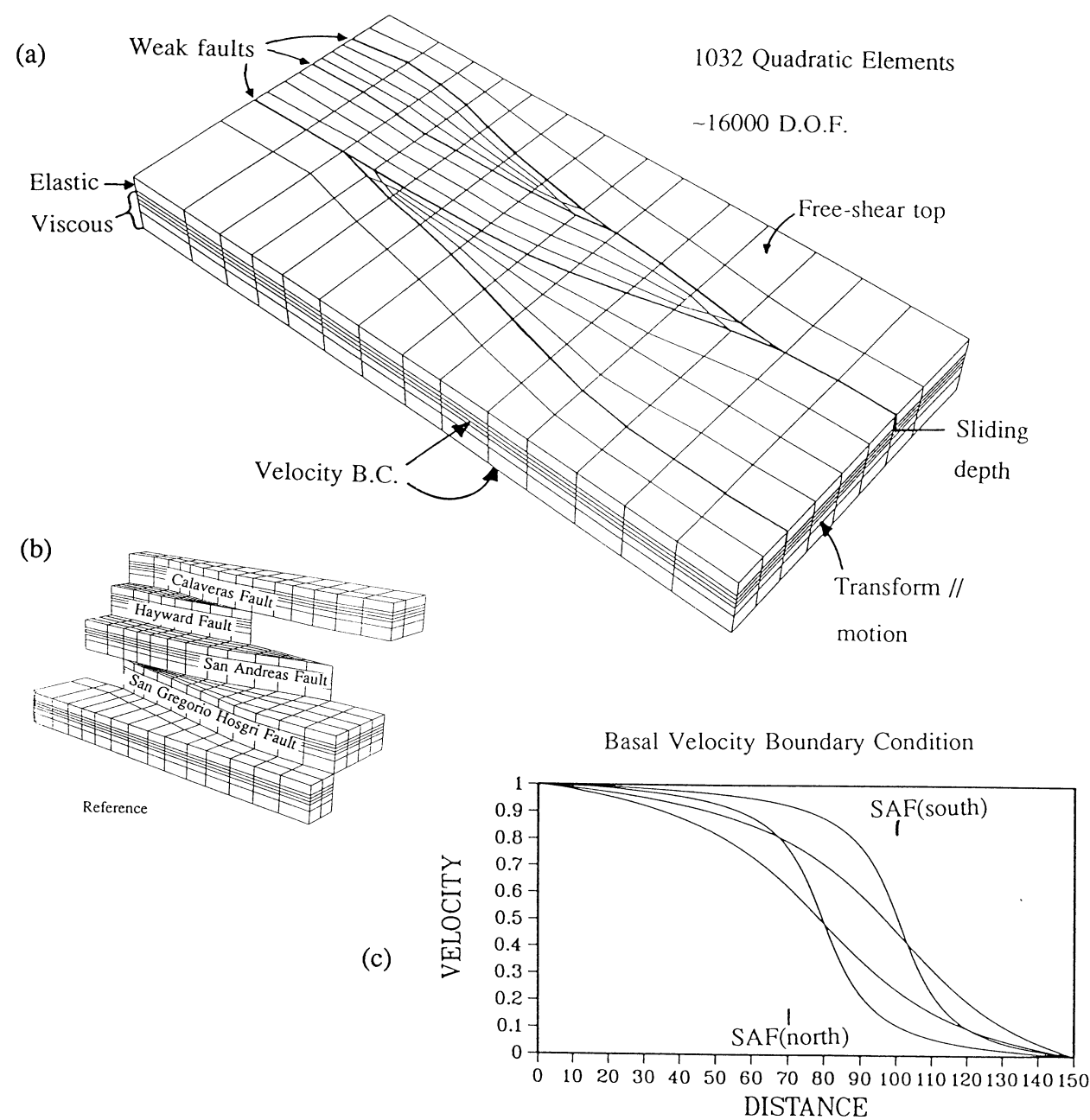
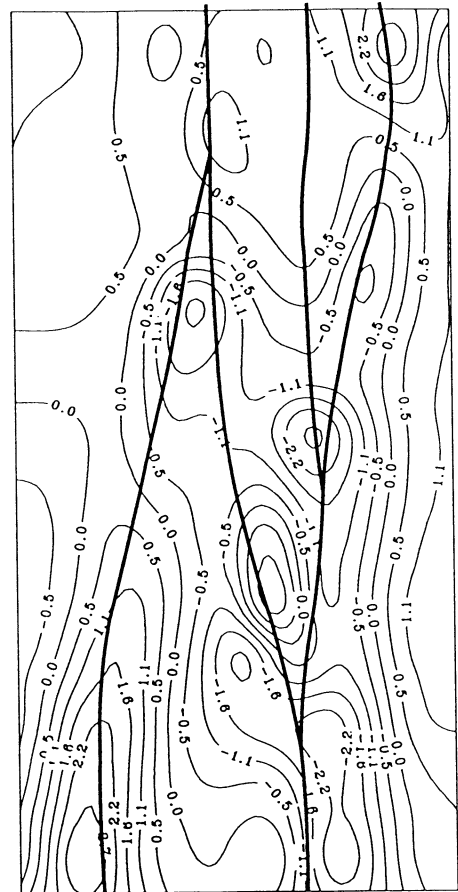
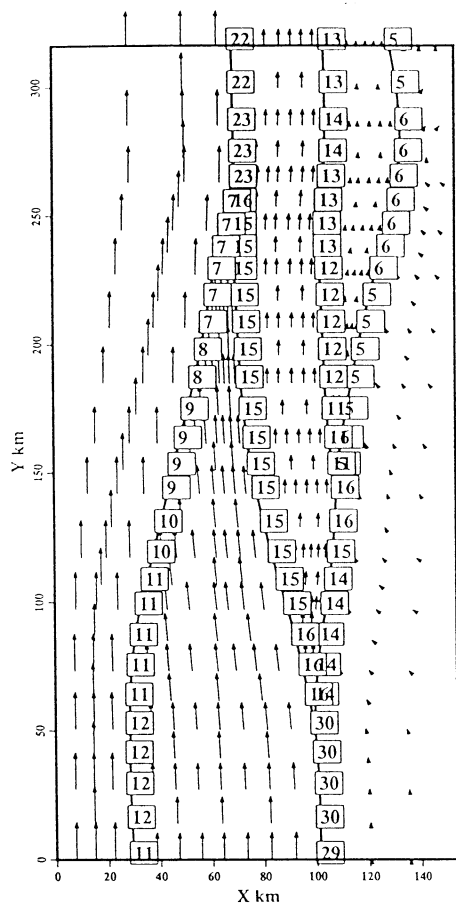


Figure 1. (a) The finite element model. (b) Exploded view of undeformed mesh, showing fault locations. (c) Several basal velocity conditions. Velocities are parallel to the long model margins, and normalized by the marginal rate.



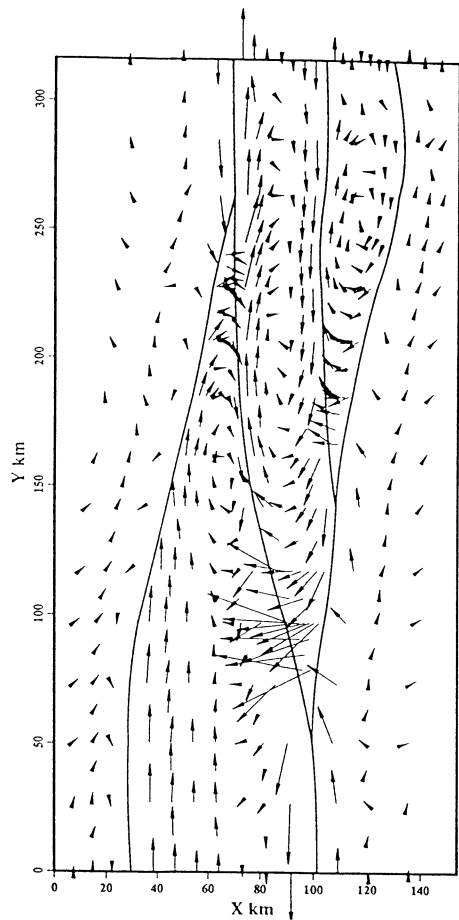


Figure 4. Velocity difference, in mm/yr, between the crust at 20 km and the surface, for the model described in Figure 2. These velocities indicate lower crustal flow, and therefore horizontal tractions acting on the base of the elastic upper crust.

Figure 5. Exploded view of crustal deformation. Block-like motion of upper crust and viscous flow of lower crust is apparent. This example is driven by a narrow, relatively easterly, mantle shear zone (Figure 1c, upper curve on right hand side).

